

Effects of aerosol chemical composition and size distribution variation on cloud albedo

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Outlines

(1) $N_{CCN}(t, x) \rightarrow N_d(t, x) \rightarrow R_C(t, x)$

$$R_C(\overline{N_{CCN}}) \stackrel{?}{=} \overline{R_C(N_{CCN})}$$

- (2) What is the error of calculated cloud albedo when variation of aerosol chemical composition is neglected?
- (3) What is the error of calculated cloud albedo when variation of aerosol size distribution is neglected?

Theoretical basis

$$R_c = \frac{\delta_c(1-g)}{2 + \delta_c(1-g)}$$

where $\delta_c = 2\pi z_c \left(\frac{3L}{4\pi}\right)^{2/3} \kappa^{1/3} N_d^{1/3}$

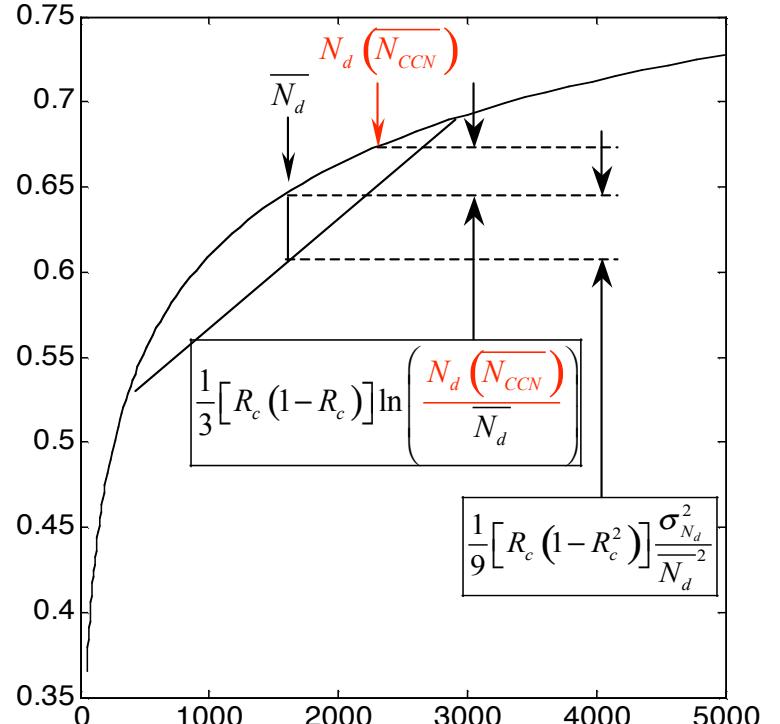
$$R_c(N_d) \approx R_c(\bar{N}_d) + \frac{dR_c}{dN_d} \Big|_{\bar{N}_d} (N_d - \bar{N}_d) + \frac{1}{2} \frac{d^2 R_c}{dN_d^2} \Big|_{\bar{N}_d} (N_d - \bar{N}_d)^2$$

$$\bar{R}_c(N_d) = R_c(\bar{N}_d) - \frac{1}{9} [R_c(1-R_c^2)] \frac{\sigma_{N_d}^2}{\bar{N}_d^2}$$

$$\Delta \bar{R}_c = R_c(N_d(\bar{N}_{CCN})) - \bar{R}_c(N_d)$$

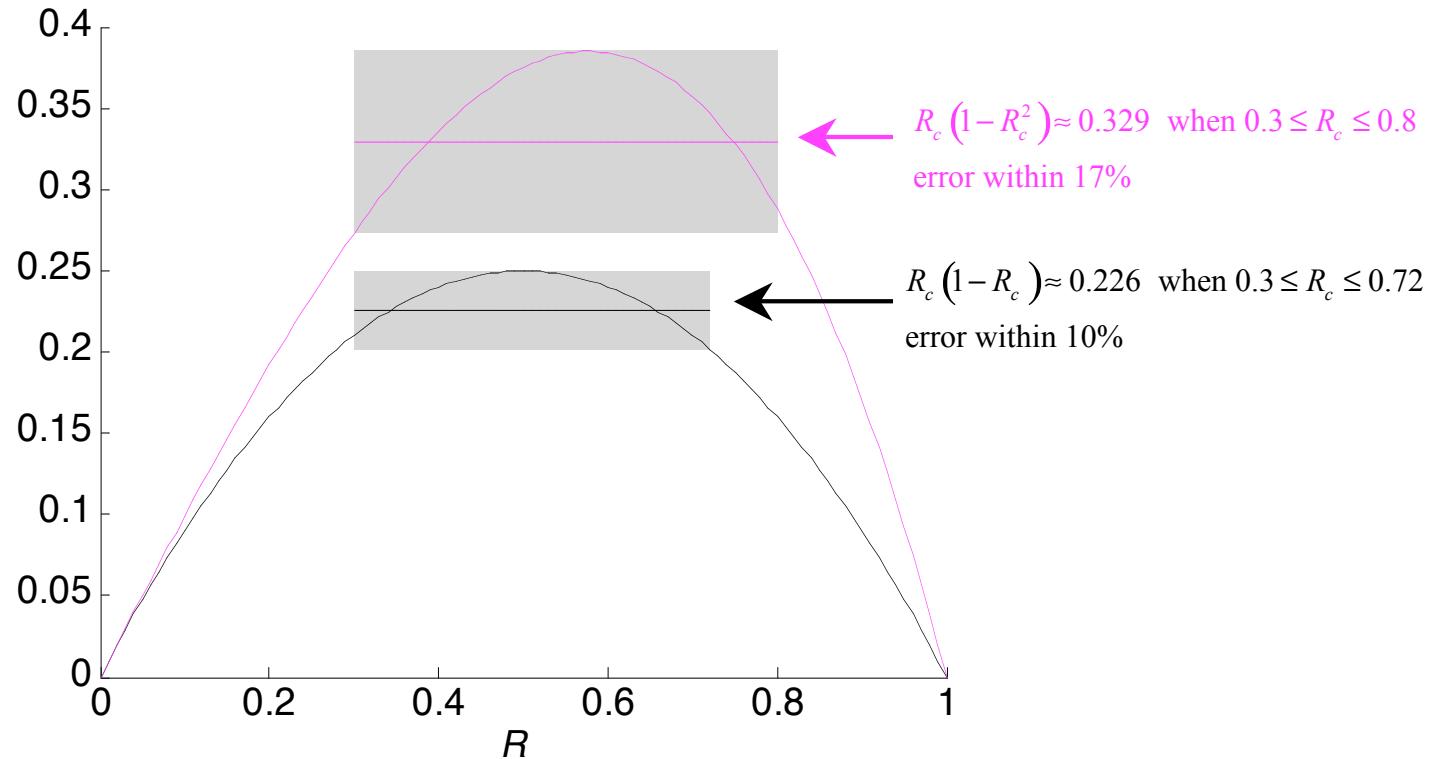
$$= R_c(N_d(\bar{N}_{CCN})) - \left[R_c(\bar{N}_d) - \frac{1}{9} [R_c(1-R_c^2)] \frac{\sigma_{N_d}^2}{\bar{N}_d^2} \right]$$

$$= \frac{1}{3} [R_c(1-R_c)] \ln \left(\frac{N_d(\bar{N}_{CCN})}{\bar{N}_d} \right) + \frac{1}{9} [R_c(1-R_c^2)] \frac{\sigma_{N_d}^2}{\bar{N}_d^2}$$

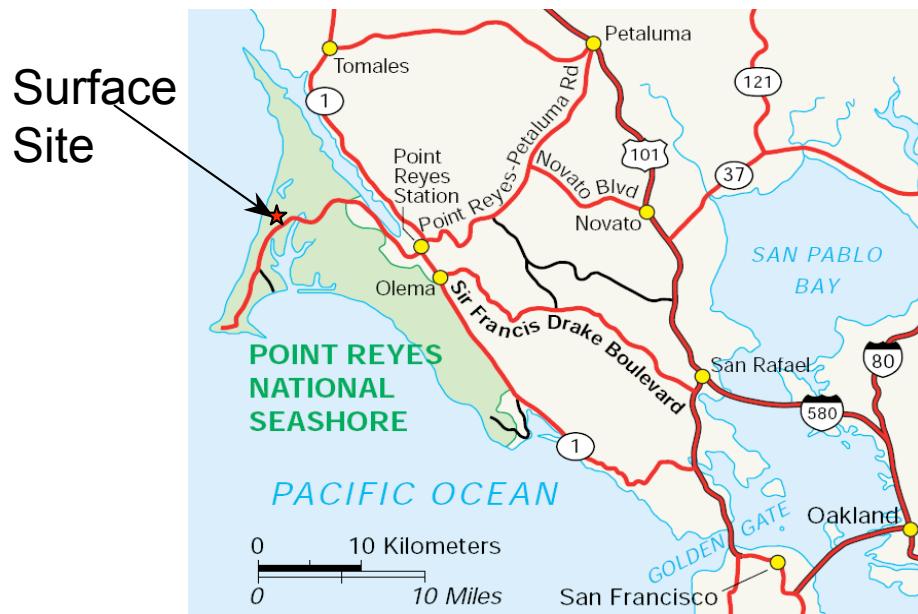


Theoretical basis

$$\begin{aligned}
 \Delta \overline{R}_c &= R_c \left(N_d \left(\overline{N_{CCN}} \right) \right) - \overline{R_c(N_d)} \\
 &= \frac{1}{3} \left[R_c (1 - R_c) \right] \ln \left(\frac{N_d \left(\overline{N_{CCN}} \right)}{\overline{N_d}} \right) + \frac{1}{9} \left[R_c (1 - R_c^2) \right] \frac{\sigma_{N_d}^2}{\overline{N_d}^2} \\
 &= \boxed{0.075 \ln \left(\frac{N_d \left(\overline{N_{CCN}} \right)}{\overline{N_d}} \right) + 0.037 \frac{\sigma_{N_d}^2}{\overline{N_d}^2}}
 \end{aligned}$$



Measurements at Pt. Reyes during MASE



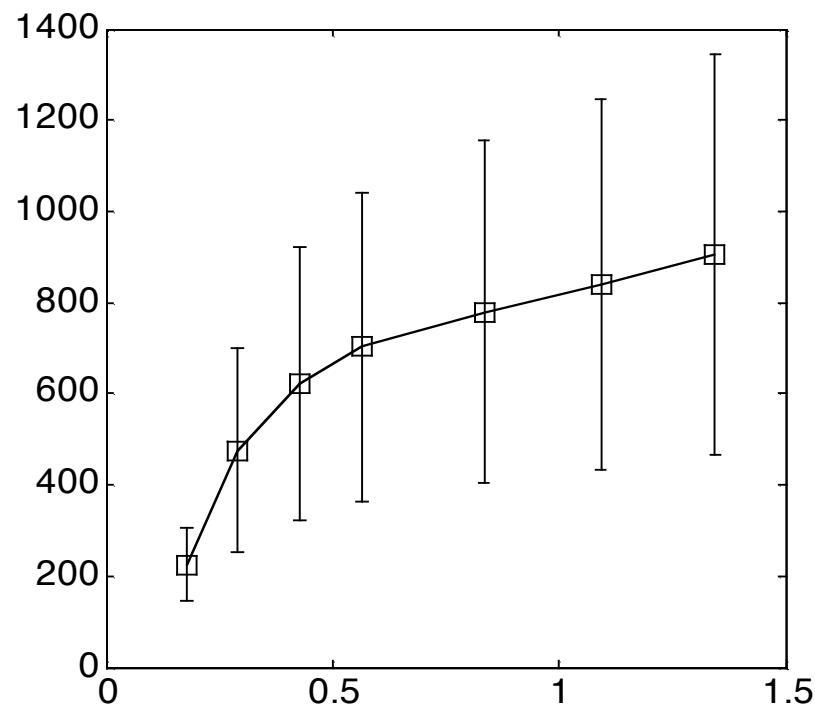
- (1) CCN spectrum measured by DMT CCN counter at 7 supersaturations ranging from 0.18% to 1.3% every 30 minutes.
- (2) Aerosol size distribution from 15 to 650 nm measured by a SMPS every 2 minutes.
- (3) Continuous measurements from July 1st to July 29th.

Measured CCN spectrum and calculated N_d

Nenes and Seinfeld (2002)

N_{CCN}

→ $N_d(N_{CCN})$



Measured CCN spectrum and calculated N_d

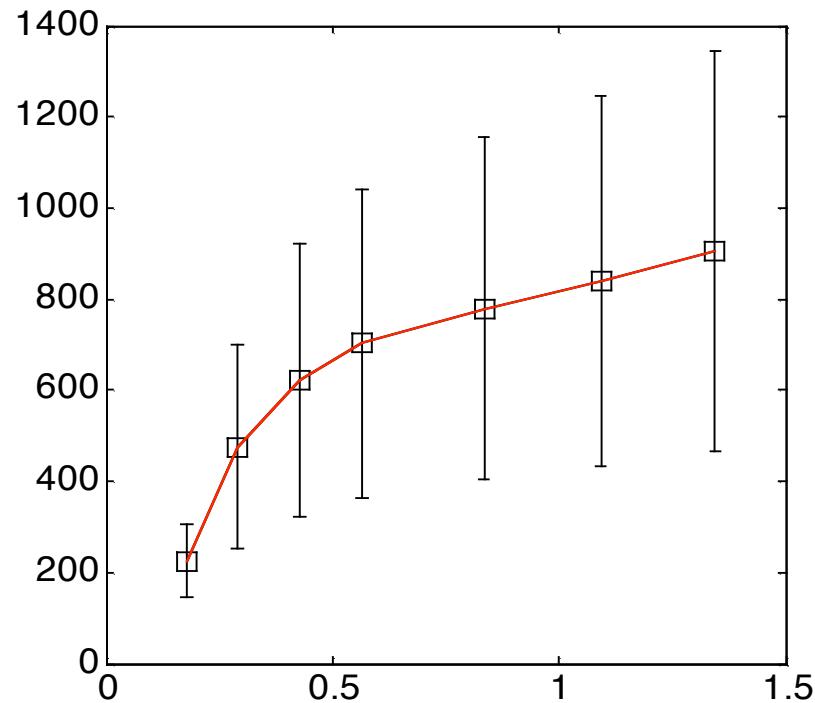
Nenes and Seinfeld (2002)

N_{CCN}

$\longrightarrow N_d(N_{CCN})$

$\overline{N_{CCN}}$

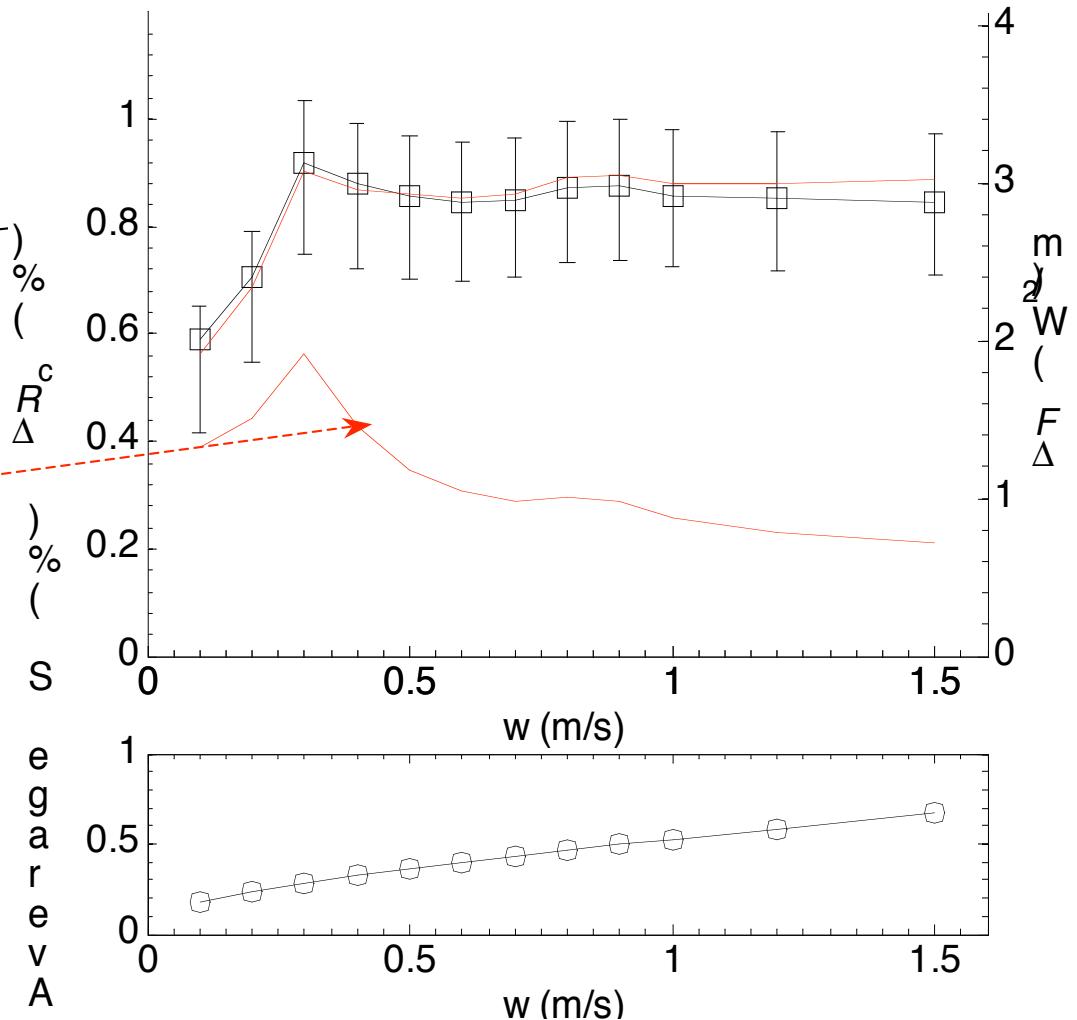
$\longrightarrow N_d(\overline{N_{CCN}})$



Results of calculated cloud albedo

$$\begin{array}{c}
 \overline{N_{CCN}} \quad N_{CCN} \\
 \downarrow \quad \downarrow \\
 N_d(\overline{N_{CCN}}) \quad N_d(N_{CCN}) \\
 \downarrow \quad \downarrow \\
 R_c = \frac{\delta_c(1-g)}{2+\delta_c(1-g)} \quad R_c(N_d) \\
 \downarrow \quad \downarrow \\
 \boxed{\Delta \overline{R}_c = R_c(N_d(\overline{N_{CCN}})) - R_c(N_d)}
 \end{array}$$

$$\boxed{\Delta \overline{R}_c} = 0.075 \ln \left(\frac{N_d(\overline{N_{CCN}})}{\overline{N_d}} \right) + 0.037 \frac{\sigma_{N_d}^2}{\overline{N_d}^2}$$

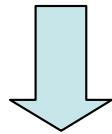


Explanations of the positive bias

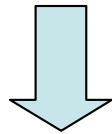
$$\overline{N_d(N_{CCN})} < \overline{N_d}(\overline{N_{CCN}})$$

Considering a extreme case:

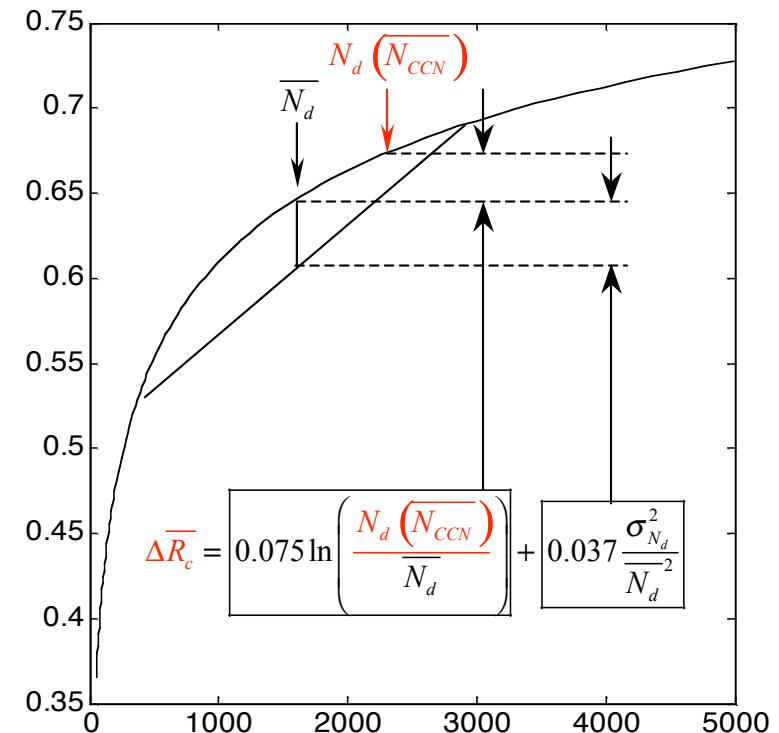
$$N_d(2 \times N_{CCN}) < 2 \times N_d(N_{CCN})$$



$$N_d(2 \times N_{CCN}) + N_d(0) < 2 \times N_d(N_{CCN})$$



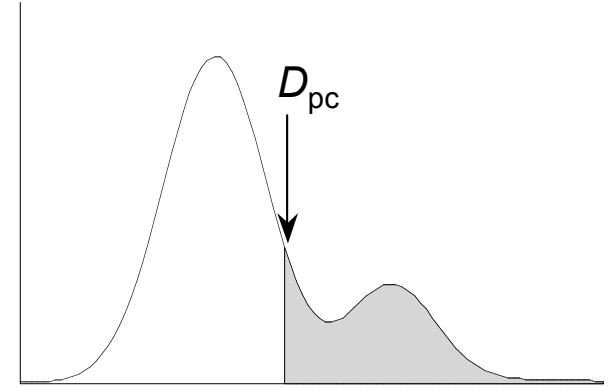
$$\frac{N_d(2 \times N_{CCN}) + N_d(0)}{2} < N_d(N_{CCN}) = N_d\left(\frac{2 \times N_{CCN} + 0}{2}\right)$$



N_{CCN} variations due to Chemical composition and size distribution variations.

$$N_{CCN,i}(s) = \int_{D_{pc,i}(s)}^{+\infty} n_i(D_p) dD_p \quad \rightarrow \quad D_{pc,i}(s)$$

$$\sum \int_{D_{pc,a}(s)}^{+\infty} n_i(D_p) dD_p = \sum N_{ccn,i}(s) \quad \rightarrow \quad D_{pc,a}(s)$$



$$n_a(D_p) = \frac{1}{k} \sum_{i=1}^k n_i(D_p) \quad \rightarrow \quad n_a(D_p)$$

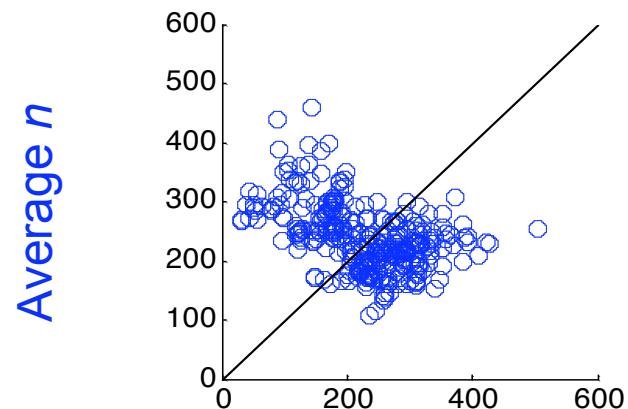
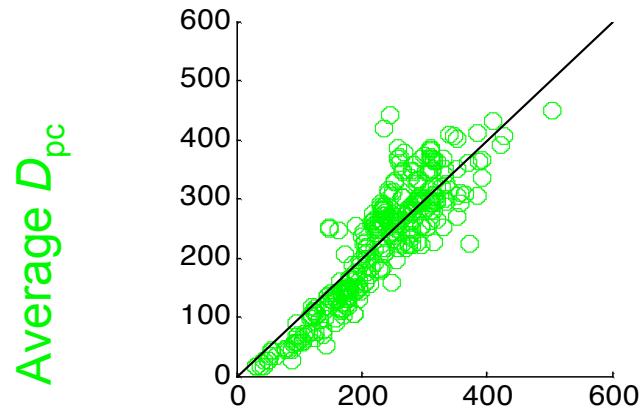
$$N_{CCN1,i}(s) = \int_{D_{pc,a}(s)}^{+\infty} n_i(D_p) dD_p$$

Neglect the variation of D_{pc}

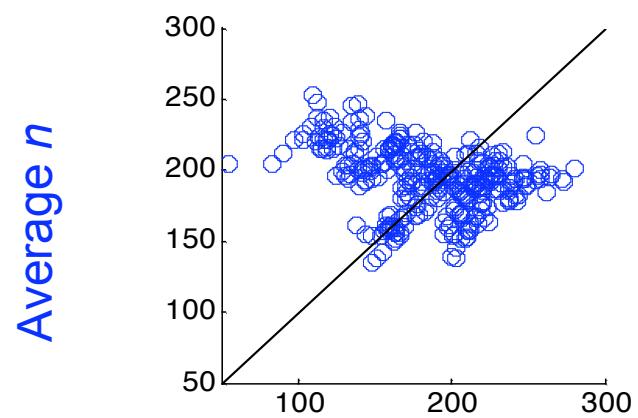
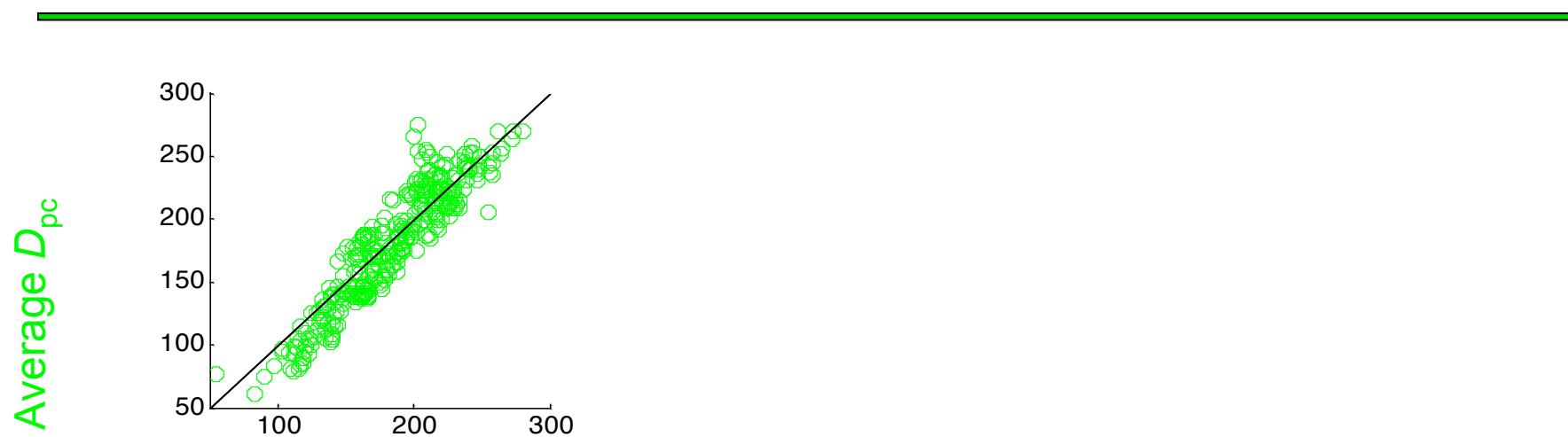
$$N_{CCN2,i}(s) = \int_{D_{pc,i}(s)}^{+\infty} n_a(D_p) dD_p$$

Neglect the variation of size distribution

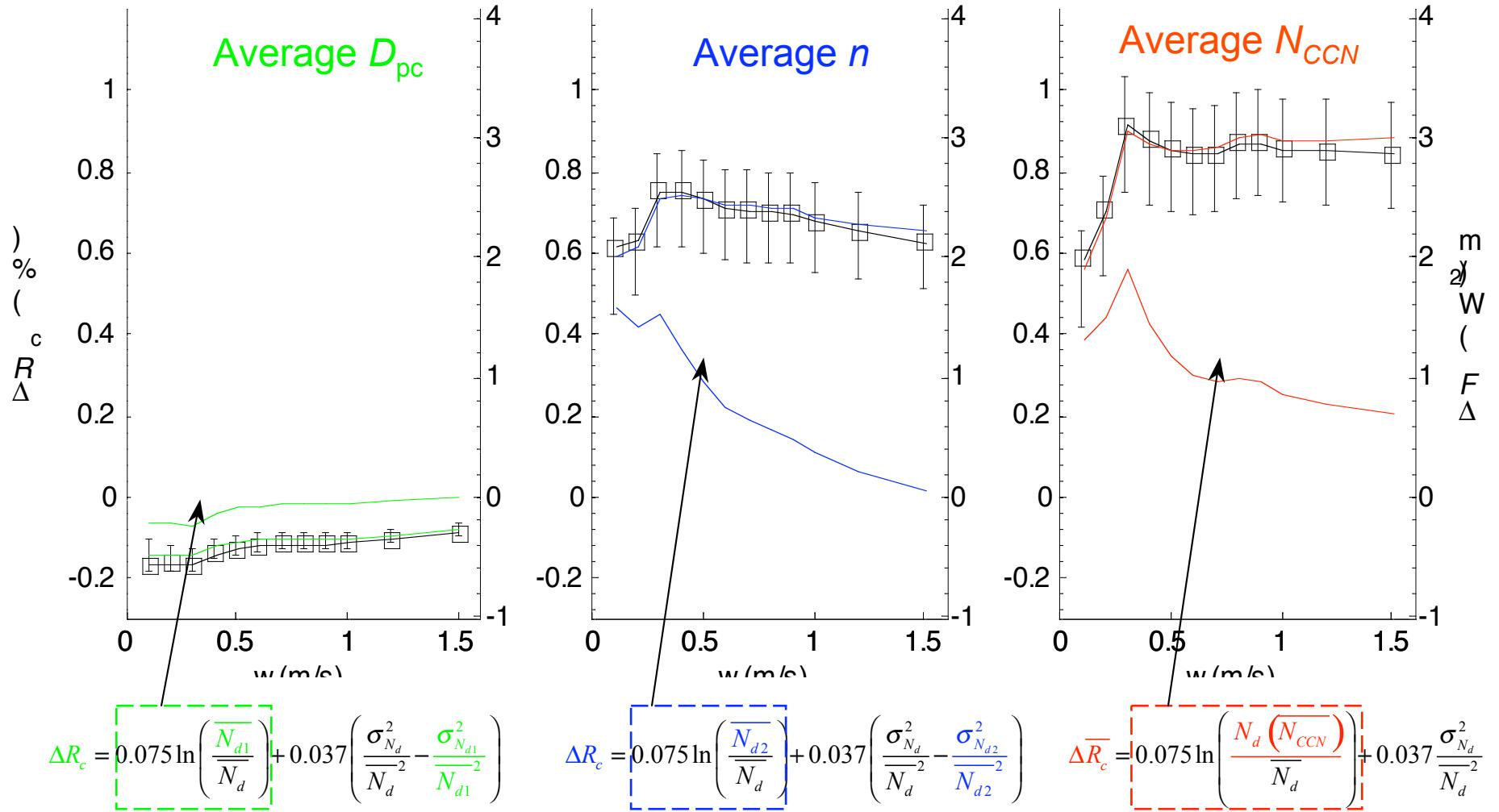
Correlations - N_{CCN}



Correlations - N_d



Results of calculated cloud albedo



Conclusions

- Neglect the variation of aerosol size distribution or CCN spectrum could lead to substantial (positive) bias in calculated cloud albedo and aerosol influence on radiation budget.
- Measurements at Pt. Reyes during MASE show that the variation of CCN spectrum was mainly caused by variation of aerosol size distribution.
- The variation of particle chemical composition could be neglected without introducing substantial error in calculated cloud albedo. This will facilitate the treatment of aerosol first indirect effect in global or regional models.

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Effects of mass accommodation coefficients

